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(21) Application number: **06141852**(71) Applicant: **SHARP CORP**(22) Date of filing: **23.06.94**(72) Inventor: **YASUO FUMITOSHI**

(54) **FOCUSED ION BEAM APPARATUS FOR
 PRODUCING CROSS-SECTION SAMPLE FOR
 TRANSMISSION ELECTRON MICROSCOPE AND
 METHOD FOR PRODUCING THE SAMPLE**

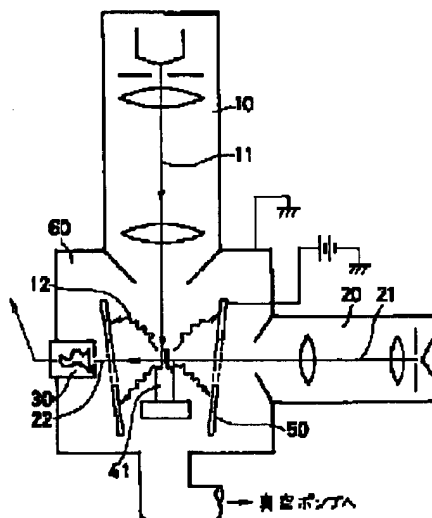
the vicinity of a position for fixing the sample 41 to surround the sample 41 for absorbing secondary electrons 12 generated by the ion beam 11 and the electron beam 21.

(57) Abstract:

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PURPOSE: To provide a focused ion beam apparatus, for producing a cross-section sample for a transmission electron microscope and a method for producing the sample Wherein a thickness of a worked surface of the sample for the transmission electron microscope can be quantitatively monitored to automatically detect a work finishing point with an optimum sample thickness and further uniformity in thickness of a part being worked can be easily determined.

CONSTITUTION: A focused ion beam apparatus comprises a working chamber 60 with a cross-section sample 41 for a transmission electron microscope placed, an ion gun 10 for emitting an ion beam 11 to the sample 41 placed in the working chamber 60, an electron gun 20 for emitting an electron beam 21 to a worked part of the sample 41 at an angle of approximately 90° with respect to the ion beam 11 emitted from the ion gun 10, a transmission electron detector 30 placed oppositely to the electron gun 20 for receiving the electron beam which has transmitted through the sample 41 to detect a current amount of the electron beam which has transmitted, and a low voltage electrode 50 placed in



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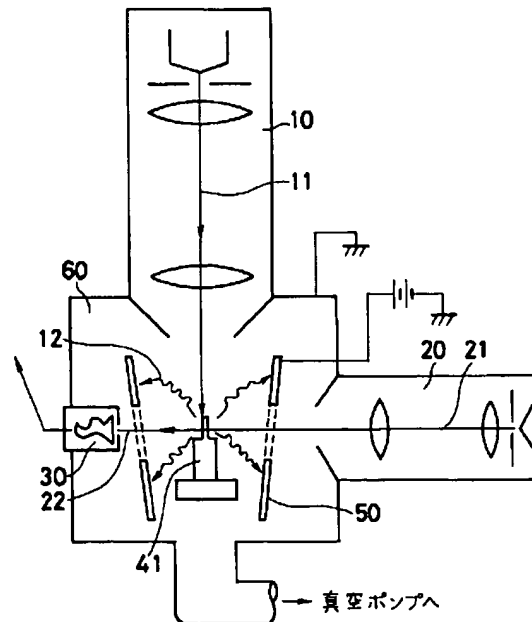
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(54) 【発明の名称】 透過電子顕微鏡用断面試料作成用集束イオンビーム装置及び透過電子顕微鏡用断面試料作成方法

(57) 【要約】

【目的】 透過電子顕微鏡用試料の加工面の厚さを定量的にモニターして最良の試料厚さで自動的に加工終了点を検出でき、更に加工中に加工部の厚さの均一性が容易に判断できる透過電子顕微鏡用断面試料作成用集束イオンビーム装置及び試料作成方法を提供する。

【構成】 透過電子顕微鏡用断面試料41を配置する加工室60と、加工室60に配置された試料41にイオンビーム11を発射するイオン銃10と、イオン銃10から発射されるイオンビーム11に対して約90度の角度で試料41の加工部分に電子ビーム21を照射する電子銃20と、該電子銃20に対向して配置されかつ試料41を透過した電子ビームを受けて透過した電子ビームの電流量を検出する透過電子検出器30と、前記試料41を固定する位置の近傍に試料41を囲むように配置され、かつイオンビーム11及び電子ビーム21により発生する2次電子12を吸収する低電圧電極50とが配設されている。



【特許請求の範囲】

【請求項1】 透過電子顕微鏡用断面試料を作成するためのイオンビームを発射するイオン銃手段と、該イオン銃手段から発射されるイオンビームに対して60度～90度程度の角度で前記透過電子顕微鏡用断面試料の加工部分に電子ビームを照射する電子銃手段と、該電子銃手段に対向して配置されかつ前記透過電子顕微鏡用断面試料を透過した電子ビームを受けて透過した電子ビームの電流量を検出する検出手段とを具備する透過電子顕微鏡用断面試料作成用集束イオンビーム装置。

【請求項2】 前記透過電子顕微鏡用断面試料を固定する位置の近傍に、イオンビーム及び電子ビームの照射により発生した2次電子を吸収する電極手段を具備する請求項1記載の透過電子顕微鏡用断面試料作成用集束イオンビーム装置。

【請求項3】 透過電子顕微鏡による断面観察を必要とする試料を透過電子顕微鏡に装着可能な厚さに切断する工程と、イオンビームによって更に観察領域を薄くする工程と、前記イオンビームで薄膜化を進めながら前記試料の加工部に電子ビームを照射する工程と、前記試料を透過する電子ビームの電流量を検出する工程と、前記検出した電流量に基づき前記試料の加工部を前記電子ビームにより走査して加工部の厚さの均一性を評価する工程とを具備する透過電子顕微鏡用断面試料作成方法。

【請求項4】 透過電子顕微鏡による断面観察を必要とする試料を透過電子顕微鏡に装着可能な厚さに切断する工程と、イオンビームによって更に観察領域を薄くする工程と、前記イオンビームで薄膜化を進めながら前記試料の加工部に電子ビームを照射する工程と、前記試料を透過する電子ビームの電流量を検出する工程と、前記検出した電流量に基づき前記試料の加工終了点を検出する工程とを具備する透過電子顕微鏡用断面試料作成方法。

【発明の詳細な説明】

【0001】

【産業上の利用分野】本発明は、透過電子顕微鏡用断面試料作成用集束イオンビーム装置及び透過電子顕微鏡用断面試料作成方法に関し、特に、LSIチップの不良箇所等の特定微小部の透過電子顕微鏡用断面試料を作成する透過電子顕微鏡用断面試料作成用集束イオンビーム装置及び透過電子顕微鏡用断面試料作成方法に関する。

【0002】

【従来の技術】最近、LSIデバイスの微細化やLSI材料薄膜化に伴い、LSIデバイス性能を決定する微細構造の観察評価が極めて重要である。特に、トランジスタのゲート絶縁膜には数nm厚の極薄膜も採用され、こうした微細構造の観察評価にはコンマ数nm以下程度の高い空間分解能が必要とされている。また、LSIデバイスの微細トランジスタのリークの原因となり、様々な不良を引き起こす結晶欠陥の評価も、LSIの性能向上や歩留まり向上において極めて重要である。これらの目

的に対応できる唯一の評価装置として透過電子顕微鏡(TEM)がある。

【0003】透過電子顕微鏡は、0.2nm程度という高分解能観察評価装置の中でも最も高い空間分解能を有しており、極薄膜化されたLSIゲート絶縁膜等まで観察評価できる唯一の手段である。また、結晶欠陥を高い空間分解能で直接観察できるのも透過電子顕微鏡だけである。更に、透過電子顕微鏡は、観察だけでなくX線マイクロアナライザー(EPM)等との複合化で1nm程度の空間分解能での元素分析が可能であり、他の分析方法の中で最も空間分解能の高いオージェ電子分光分析法(AES)と比較しても1/20程度の空間分解能を有しており、微細化の進むLSIデバイス解析において極めて有用な解析手法に位置付けされている。

【0004】透過電子顕微鏡による観察評価には、試料を透過した電子線の投影像が用いられる。このため、透過電子顕微鏡用の試料は電子線を透過できる厚さに加工する必要がある。具体的には、500nm以下程度の薄膜化が必要であり、特に結晶構造等を評価するための高分解能観察を行うには試料を100nm以下程度まで薄膜化する必要がある。

【0005】一般に、LSIの透過電子顕微鏡用試料作成は機械的に試料を薄くした後に、イオンビームで最終の薄膜化が行われているが、これは広い範囲に形成された薄膜や、同一形状が繰り返されるLSIパターンの任意の場所を対象とした場合であり、微細化されたLSIの特定箇所、例えば故障トランジスタやオープンコンタクト等を評価する場合、薄膜化の加工部の位置がずれると観察評価箇所が失われる虞があるため、透過電子顕微鏡用試料作成では1μm以下の位置精度で特定箇所を薄膜化する必要がある。これには、単純な機械研磨とイオンビーム加工では対応が不可能であり、幾つかの試料加工方法が案出されている。

【0006】以下、LSIチップの不良箇所等の特定微小部の断面の透過電子顕微鏡観察や分析を行うための透過電子顕微鏡用試料を機械研磨により加工する方法について図4a～図4gを用いて説明する。

【0007】(1-1)顕微鏡を具備したレーザマーカあるいは集束イオンビーム装置等により、図4aに示すように、透過電子顕微鏡観察を所望する特定微小部42周辺に穴開けによりマーキング43を行う。なお、特定微小部42がマーキング43のためのレーザやイオンビーム照射の熱的影響や穴開けの飛散物汚染を受けないように、マーキングは特定微小部42から20μm程度以上離れた位置に行うとよい。マーキングの大きさや深さについては、後の加工での位置確認の点では大きいほどよい反面、マーキングの際の熱や飛散物を抑える必要性から大きさは5μm以下程度、深さは1～5μm程度が良いと考えられる。試料加工に実体顕微鏡等の低倍率顕微鏡を用いる必要がある場合には、前記マーキング

に加えて特定微小部42から更に40 μm 以上離れた位置に大きさ10 μm 程度のマーキングを追加するとよい。

【0008】(1-2)表面保護のため試料41の表面にガラス44を貼着する。

【0009】(1-3)マーキングを参考にして、ダイシングマシンの高速回転外周刃61により観察または分析を所望する特定微小領域周辺を透過電子顕微鏡に導入可能な1.5mm \square 以下程度に切断する。この際、切断面としては、図4b、4cに示すように、透過電子顕微鏡用の試料41の観察または分析を所望する断面と平行な面及びこれに垂直な面を選択する。試料41の観察/分析を所望する断面に垂直な方向の切断幅は、狭いほうが次の研磨で時間短縮できるため、切断時に観察または分析を所望する特定微小部42が破損しない範囲、例えば100~200 μm 幅で狭く切断する。

【0010】(1-4)試料41の観察または分析を希望する断面と平行な二つの切断面を、図4d、4eに示すように、研磨治具70と回転研磨盤71とにより機械研磨する。この際、マーキングを参考にして一側面が観察/分析を希望する特定微小部42に対して10 μm 程度の距離になるまで研磨する。試料41の一側面と対向する他側面を特定微小部42から70 μm 程度の距離になるまで研磨する。これによって研磨面の間隔である試料41の幅は80 μm 程度になる。なお、ここまでの研磨は、比較的研磨速度の速い5~15 μm 程度の研磨粒を用いる。特定微小部42に近い試料41の一側面である研磨面は、この段階で更に細かい1 μm 以下の研磨粒を用いて鏡面仕上げを行う。

【0011】(1-5)試料41を、図4fに示すように、特定微小部42から遠い試料41の他側面である鏡面仕上げをしていない研磨面を上にして回転ステージ73上に固定し、回転研磨ディスク72により観察/分析所望部を中心にディンプルグラインダー研磨する。ディンプルグラインダー研磨は、まず5~10 μm の研磨材を用いて分析/観察希望部付近の厚さが20~30 μm になるまで研磨する。それから、1 μm 以下の研磨粒を用いて分析/観察希望部の鏡面仕上げを行う。

【0012】(1-6)試料41の分析/観察希望部を中心に、図4gに示すように、透過電子顕微鏡用メッシュ80に貼る。

【0013】(1-7)イオンミリング装置により両面よりイオンミリングし、500nm以下の厚さを得る。

【0014】(1-8)透過電子顕微鏡により試料41の観察分析を行う。

【0015】次に、特開平2-132345号公報及び特開平5-180739号公報に開示されている集束イオンビーム装置による透過電子顕微鏡用試料の加工方法について図5a~図5gを用いて説明する。

【0016】(2-1)前述の(1-1)、(1-3)

と同様の方法により、図5a~図5cに示すように、試料にマーキングを行うと共に試料41の切断を行う。必要に応じて更に試料の観察/分析希望領域を、図5dに示すように、ダイシングマシンの高速回転外周刃61により薄く削る。

【0017】(2-2)集束イオンビーム装置により観察/分析希望の特定微小部42付近に集束イオンビーム11を、図5e、5fに示すように、試料表面方向より照射する。この際、集束イオンビーム11は、図5gに示すように、観察/分析希望断面と平行な一辺を有する長方形領域81、82にラスタ走査し、この領域をスパッタエッチングする。集束イオンビーム11のビーム電流やビーム径等を適当に選択しながらラスタ走査領域を徐々に観察/分析希望断面に近付け、図5fに示すように、断面加工を行う。この加工を観察/分析希望の特定微小部42の両側から行うことでこの微小部の薄膜化を行い、透過電子顕微鏡の試料とする。

【0018】なお、集束イオンビーム11は、図6(c)に示すように、逆円錐形であり、試料表面に対して垂直にビーム照射すると、垂直断面が得られない。よって、図6(c)に示すように、試料41を所定角度 θ だけ傾けて垂直断面を得る。この角度 θ は集束イオンビーム装置や加工条件によって異なるため、事前に条件出しを行う必要があり、一般的には3~5度程度の傾斜で加工が行われている。また、実際の加工の際には、断続的に加工を中断し、加工形状を集束イオンビームによる2次イオン像や2次電子像観察、走査型電子顕微鏡に試料を移しての観察、電子線照射機能を有する集束イオンビーム装置では装置内にて電子線照射による2次電子像観察等によって評価し、不具合があれば集束イオンビームの調整や条件変更、試料の角度調整を適宜行う。

【0019】(2-3)試料41の分析/観察希望部を中心に、図5gに示すように、透過電子顕微鏡用メッシュ80に貼る。

【0020】(2-4)透過電子顕微鏡により試料41の観察分析を行う。

【0021】集束イオンビーム加工の終了点は以下の方法により決定する。

【0022】(1)イオンビーム照射によって得られる2次イオン像や2次電子像等で加工部の形状観察を行い、加工部の厚さを観察像から判断し、加工終了点を決定する。なお、画像分解能は数十nmである。

【0023】(2)集束イオンビーム加工と走査型電子顕微鏡観察とを交互に行い、走査型電子顕微鏡による加工部の観察像から加工部の厚さを判断し、加工終了点を決定する。あるいは、集束イオンビーム加工と走査型電子顕微鏡観察とを交互に行い、透過電子顕微鏡観察像の解像度から試料完成度を判定する。

【0024】(3)特開平4-76437号公報に開示されているように、イオン銃とは別に電子銃を具備した

集束イオンビーム装置あるいはイオン銃を使って電子ビームが照射できる集束イオンビーム装置においては、集束イオンビーム装置内で集束イオンビーム加工と電子ビームによる観察を交互に行い、観察像から加工部の厚さを判断し、加工終了点を決定する。

【0025】

【発明が解決しようとする課題】従来の機械研磨による透過電子顕微鏡用試料の加工方法では、観察評価を希望する微小部に対して加工位置精度が機械研磨の段階で数 μm であり、LSI の不良箇所を観察するための加工に必要な $1\mu\text{m}$ 以下の精度が得られない。

【0026】従来の集束イオンビーム装置による透過電子顕微鏡用試料の加工方法では、集束イオンビームによる2次イオン像や2次電子像観察で加工形状を評価する場合、あるいは集束イオンビームによる2次イオン像や2次電子像観察で加工面の厚さを評価して加工終了点を判断する場合、加工目標厚さが数十～百数十 nm であるのに対して、集束イオンビームのビーム系が最小で 100nm 程度であり、得られる2次イオン像や2次電子像の分解能もイオンビーム径に準じるため、画像上で正確な厚さの判断が難しく、試料作成の成功率が低くなる。集束イオンビームでの観察は加工と交互に行うため、加工終了点を超過して加工する虞がある。逆円錐状の集束イオンビームで断面加工を行うため、図6(c)に示すように試料を傾斜させて加工するが、集束イオンビームの調整ばらつき等から加工毎に加工断面は表面に対して垂直な面からずれてしまう。例えば、加工面両面の角度が2度傾斜している場合、最表面の各部の幅に対して $3\mu\text{m}$ 深さの位置では厚さは 100nm のずれが生じる。この状態で最表面9にて加工部の幅が目標の 100nm に達した場合、傾きの方向によって $3\mu\text{m}$ の深さでは 200nm の幅もしくは 0nm となり、穴が開くことになる。深さ $3\mu\text{m}$ はLSI デバイス構造の表面からの厚さに相当する。また、加工部の幅が 200nm では、格子像観察等の高分解能観察は困難である。こうした加工面の垂直方向に対する角度誤差を集束イオンビームによる観察分解能で、しかも上方からの観察で評価することは不可能であり、観察評価希望部の各厚さを正確に評価できないため、透過電子顕微鏡用試料作成の成功率は低くなる。

【0027】集束イオンビームによる加工形状や加工終了点を走査型電子顕微鏡で判断する場合、もしくは透過電子顕微鏡による観察像で判断する場合、集束イオンビーム加工と電子顕微鏡観察を交互に行うため、試料の入れ替え等に時間を要し、加工時間が長くなる。一般に加工時間は3～5時間であるのに対して観察を加えると試料交換、観察、集束イオンビーム再調整で1回最低1時間程度の時間を必要とし、2～3回の観察を加えるだけで集束イオンビーム加工の開始から終了までの所要時間の1.5から2倍となる。集束イオンビーム加工と電子

顕微鏡観察を交互に行う場合、集束イオンビームでの再加工の際に、図6(a)、(b)に示すように、試料の入れ替えによって加工方向に誤差が生じ、観察部の厚さが不均一になり、良好な観察が困難になる。電子顕微鏡では、観察分解能は数 nm 以下であり、イオンビームによる観察法に比べて加工部表面の厚さは正確に評価できる。但し、加工形状の観察評価、例えば加工面の垂直方向に対する角度誤差は上方からの観察で評価することは困難であり、観察希望部の正確な膜厚評価はできない。観察後、再び集束イオンビーム加工を行う際には、集束イオンビームは再調整が必要であり、条件が変わり、評価結果からのフィードバックもできない。

【0028】電子ビーム照射機能を具備した集束イオンビーム装置において、集束イオンビーム加工の終了点の判断を電子ビームにより得られる2次電子像等の観察で行う場合、イオン銃が電子銃を兼用している場合はもとより、イオン銃とは別に電子銃を持つ場合でも、集束イオンビーム加工中はイオンビーム照射によって発生する2次電子のため、電子ビームによる2次電子像観察はできない。従って、加工と観察とを同時にはできず、加工終了点を超過して加工する虞がある。加工部上方からの観察のため、加工面の垂直方向に対する傾きは正確に評価できない。

【0029】本発明は、上記のような課題を解消するためになされたもので、透過電子顕微鏡用試料の加工面の厚さを定量的にモニターして最良の試料厚さを自動的に検出でき、更に加工中に加工部の厚さの均一性が容易に判断できる透過電子顕微鏡用断面試料作成用集束イオンビーム装置及び透過電子顕微鏡用断面試料作成方法を提供することを目的とする。

【0030】

【課題を解決するための手段】本発明によれば、前述の目的は、透過電子顕微鏡用断面試料を作成するためのイオンビームを発射するイオン銃手段と、該イオン銃手段から発射されるイオンビームに対して $60^\circ \sim 90^\circ$ 程度の角度で前記透過電子顕微鏡用断面試料の加工部分に電子ビームを照射する電子銃手段と、該電子銃手段に対向して配置されかつ前記透過電子顕微鏡用断面試料を透過した電子ビームを受けて透過した電子ビームの電流量を検出する検出手段とを具備する請求項1の透過電子顕微鏡用断面試料作成用集束イオンビーム装置によって達成される。

【0031】本発明によれば、前述の目的は、前記透過電子顕微鏡用断面試料を固定する位置の近傍に、イオンビーム及び電子ビームの照射により発生した2次電子を吸収する電極手段を具備する請求項2の透過電子顕微鏡用断面試料作成用集束イオンビーム装置によって達成される。

【0032】本発明によれば、前述の目的は、透過電子顕微鏡による断面観察を必要とする試料を透過電子顕微

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鏡に装着可能な厚さに切断する工程と、集束イオンビームによって更に観察領域を薄くする工程と、集束イオンビームで薄膜化を進めながら試料の加工部に電子ビームを照射する工程と、試料を透過する電子ビームの電流量を検出する工程と、前記検出した電流量に基づき試料の加工部を電子ビームにより走査して加工部の厚さの均一性を評価する工程とを具備する請求項 3 の透過電子顕微鏡用断面試料作成方法によって達成される。

【0033】本発明によれば、前述の目的は、透過電子顕微鏡による断面観察を必要とする試料を透過電子顕微鏡に装着可能な厚さに切断する工程と、集束イオンビームによって更に観察領域を薄くする工程と、集束イオンビームで薄膜化を進めながら試料の加工部に電子ビームを照射する工程と、試料を透過する電子ビームの電流量を検出する工程と、前記検出した電流量に基づき試料の加工終了点を検出する工程とを具備する請求項 4 の透過電子顕微鏡用断面試料作成方法によって達成される。

【0034】

【作用】請求項 1 の透過電子顕微鏡用断面試料作成用集束イオンビーム装置によれば、イオン銃手段により集束イオンビームを試料表面に対して任意の加速電圧、ビーム電流、ビーム径で照射し、試料表面の任意の領域をラスタ走査する。イオンビーム加工中に、電子銃手段により任意の加速電圧、ビーム電流、ビーム径で加工面の任意の位置に電子ビームをイオンビームに対して 60 度～90 度程度の角度で試料に照射し、試料を透過した電子ビームを検出手段により受け、検出手段により透過した電子ビームの電流量を検出し、透過ビームの電流値が予め設定された値に達した段階で集束イオンビームにより加工を終了する。

【0035】請求項 2 の透過電子顕微鏡用断面試料作成用集束イオンビーム装置によれば、任意の正の電圧が印加された電極手段により試料に照射された集束イオンビームによる 2 次電子等の電子を吸収し、検出手段に達して透過電子ビーム電流量検出の妨げとならないようにする。

【0036】請求項 3 の透過電子顕微鏡用断面試料作成方法によれば、透過電子顕微鏡用断面試料を作成する際、透過電子顕微鏡による断面観察を必要とする試料を透過電子顕微鏡に装着可能な厚さに切断し、集束イオンビームによって更に観察領域を薄くし、集束イオンビームで薄膜化を進めながら加工部に電子ビームを照射し、その透過ビームの電流量を検出し、検出した電流値に基づき前記試料の加工部分の厚さの均一性を評価し、この評価に基づき均一な厚さの透過電子顕微鏡用断面試料を作成する。

【0037】請求項 4 の透過電子顕微鏡用断面試料作成方法によれば、透過電子顕微鏡用断面試料を作成する際、透過電子顕微鏡による断面観察を必要とする試料を透過電子顕微鏡に装着可能な厚さに切断し、集束イオン

ビームによって更に観察領域を薄くし、集束イオンビームで薄膜化を進めながら加工部に電子ビームを照射し、試料を透過する電子ビームをモニタし、加工終了点を検出する工程により透過電子顕微鏡用断面試料を作成する。

【0038】

【実施例】以下、請求項 1 の透過電子顕微鏡用断面試料作成用集束イオンビーム装置の実施例を図 1 を参照しながら説明する。本実施例は、透過電子顕微鏡用試料の加工面の厚さを定量的にモニターして最良の試料厚さを自動的に検出でき、更に加工中に加工部の厚さの均一性が容易に判断できる透過電子顕微鏡用断面試料作成用集束イオンビーム装置を提供することを課題とする。

【0039】本実施例は、透過電子顕微鏡用断面試料 41 を配置する加工室 60 と、加工室 60 に配置された試料 41 にイオンビーム 11 を発射するイオン銃手段としてのイオン銃 10 と、イオン銃 10 から発射されるイオンビーム 11 に対して約 90 度の角度で試料 41 の加工部分に電子ビーム 21 を照射する電子銃手段としての電子銃 20 と、該電子銃 20 に対向して配置されかつ前記透過電子顕微鏡用断面試料 41 を透過した電子ビームを受けて透過した電子ビームの電流量を検出する検出手段としての透過電子検出器 30 と、前記試料 41 を固定する位置の近傍に試料 41 を囲むように配置され、かつイオンビーム 11 及び電子ビーム 21 により発生する 2 次電子 12 を吸収して正確な透過ビーム電流量が測定できなくなるのを防止する電極手段としての低電圧電極 50 とを具備している。

【0040】試料 41 は、図示しない試料導入系によって加工室 60 内部に搬送され、図示しないステージ駆動系によって適宜駆動されるように構成されている。イオンビーム 11 及び電子ビーム 21 はそれぞれラスタ走査可能であり、図示しない 2 次イオン検出器あるいは 2 次電子検出器によりそれぞれのビームの照射領域の形状観察が行えるように構成されている。なお、本実施例の動作は後述の透過電子顕微鏡用断面試料作成方法の実施例と同じなので説明を省略する。

【0041】次に、請求項 3 及び 4 の透過電子顕微鏡用断面試料作成方法の実施例について図 2 a～図 2 g 及び図 3 a～図 3 h を参照しながら説明する。本実施例は、透過電子顕微鏡用試料の加工面の厚さを定量的にモニターして最良の試料厚さを自動的に検出でき、更に加工中に加工部の厚さの均一性が容易に判断できる透過電子顕微鏡用断面試料作成方法を提供することを課題とする。

【0042】LSI チップ 41 上の不良トランジスタ等を透過電子顕微鏡による断面観察／分析を希望する特定微小部 42 の周囲に集束イオンビーム装置あるいは顕微鏡を具備したレーザマーカ等により、図 2 a に示すように、穴開けによりマーキング 43 を行う。なお、特定微小部 42 がマーキング 43 のためのレーザやイオン

ビーム照射の熱的影響や穴開けの飛散物汚染を受けないように、マーキングは特定微小部 42 から $20\mu\text{m}$ 程度以上離れた位置に行くとよい。マーキングの大きさや深さについては、後の加工での位置確認の点では大きいほどよい反面、マーキングの際の熱や飛散物を抑える必要性から大きさは $5\mu\text{m}$ 以下程度、深さは $1\sim 5\mu\text{m}$ 程度が良い。マーキングを参考にして、ダイシングマシン的高速回転外周刃 61 により観察または分析を所望する特定微小領域周辺を透過電子顕微鏡に導入可能な 1.5mm 以下程度に切断する。

【0043】この際、切断面としては、図 2b に示すように、透過電子顕微鏡用の試料 41 の観察または分析を所望する断面と平行な面を選択する。試料 41 の観察／分析を所望する断面に垂直な方向の切断幅は、狭いほうが後の集束イオンビーム加工の範囲が小さくできるため、垂直な方向の切断幅は、切断時にチップング等で観察／分析を所望する特定微小部 42 が破損しない範囲、例えば $100\sim 200\mu\text{m}$ 幅で狭く切断する。必要に応じて更に試料の観察／分析希望部表面近傍を、図 2d に示すように、更にダイシングマシン的高速回転外周刃 61 により薄く削る。

【0044】加工した LSI チップを集束イオンビーム装置に導入する。集束イオンビーム装置内に LSI チップを導入する際、LSI チップの向きは、加工断面が集束イオンビーム装置内部の電子銃 20 に対して対向するように設定する。集束イオンビーム装置にてラスタ走査により観察／分析希望断面を一边とする長方形領域 81、82 に集束イオンビーム 11 を照射し、観察／分析希望断面の薄膜化加工を行う。長方形領域 81 は透過電子検出器 30 と対向しており、長方形領域 82 は集束イオンビーム装置内の電子銃 20 と対向する断面を含む領域である。この集束イオンビーム加工に際しては、まず領域 81 の加工を行う。領域 81 の加工は段階的に集束イオンビーム 11 のビーム電流／ビーム径を下げながら断面加工の位置精度や加工面の均一性を高める。

【0045】一般的な加工条件は、加速電圧 $25\sim 30\text{kV}$ 、Ga イオンビームを用い、ビーム電流 2000pA 程度で目標とする特定微小部 42 から数 μm 離れた位置まで加工し、続いてビーム電流 400pA 程度で特定微小部 42 から $1\mu\text{m}$ 離れた位置まで加工する。更に、ビーム電流 100pA 程度で特定微小部 42 を含む位置まで加工し、最終的にビーム電流数十 pA 程度のビームで加工面の仕上げを行う。なお、集束イオンビーム 11 は逆円錐形であり、試料表面に対して垂直にビーム照射すると、垂直断面が得られないので、試料 41 をビーム条件に応じて $3\sim 5$ 度程度傾斜して加工を行う。

【0046】領域 81 の加工完了後、同様の方法により領域 82 の加工を行う。領域 82 の加工において、加工部の厚さが $1\mu\text{m}$ 程度になった段階で、観察／分析希望断面にほぼ垂直に電子ビーム 21 を照射し、試料の断面

加工部を透過した透過電子を透過電子検出器 30 により検出する。

【0047】電子ビームの加速電圧は 10kV 以上に設定する。シリコンの場合、加速電圧 10kV 以上であれば電子ビームは $1\mu\text{m}$ の厚さを透過する。よって、この電子ビーム照射により検出器 30 で透過電子が検出される。なお、検出器 30 としては、高感度で検出速度の速いチャンネルトロンなどが有効であるが、試料の材質や電子ビーム電流の設定によってファラデーカップ等も使用できる。検出器 30 に印加する電圧や電子ビームの電流は検出される透過電子ビーム電流に応じて適当に設定する。電子ビームを図 3a、3b のように同一材料の範囲で上下、左右に操作し、この間の透過ビーム電流を検出すると、加工部の厚さが均一な場合、図 3c に示すように、均一な波形が得られる。一方、図 3e、3f、及び 3g に示すように、加工部の厚さが不均一な場合、透過ビーム電流波形は図 3d に示すような波形となる。この段階で確認された加工部の不均一は、これ以降の加工における集束イオンビーム形状や試料角度等の補正で最終的に修正可能である。

【0048】透過ビーム電流検出を続けながら集束イオンビーム加工により領域 82 の加工を行う。加工分の厚さが薄くなるにつれて透過ビーム電流が増加する。検出される透過ビーム電流の増加に合わせて電子ビーム 21 の加速電圧を段階的に下げると、図 3h に示すように、電子ビームの透過厚さも下がるので、適切に加速電圧を選択すれば透過ビーム電流変化によって加工部の厚さの変化を正確に検知できる。シリコン材料の場合、最終的な電子ビーム 21 の加速電圧を 3kV 以下程度に設定すれば、透過ビーム電流の値で $500\sim 1000\text{A}$ 程度の厚さを検出できる。事前に良好な透過電子顕微鏡試料を用いて透過電流量の条件出しを行い、加工終了点とする透過ビーム電流量を決定しておけば、自動的に加工終了点を検知できる。

【0049】なお、この透過電子ビーム検出の際には、低電圧電極 50 に正の低い電位を与え、集束イオンビーム照射によって発生する多量の 2 次電子 12 を回収することで、透過電子ビーム電流検出精度劣化を防止し、集束イオンビーム照射中でも透過電子ビーム電流検出が可能となり、加工の超過を防ぐ。

【0050】また、イオンビームや電子ビームへの悪影響を防ぐため、低電圧電極 50 の材料には非磁性金属を用い、磁化を防ぐ。低電圧電極 50 に印加する電圧は、数 $\text{kV}\sim 30\text{kV}$ 程度の集束イオンビームや電子ビーム軌道に影響を与えず、かつ集束イオンビーム照射で発生した数十 eV の 2 次電子の回収効率が上がるように $+ 数十\text{V}$ に設定する。

【0051】領域 81 を先に加工する理由については、透過電子検出器 30 と対向する断面側の加工領域 81 に集束イオンビーム 11 を照射している状態では、集束イ

オンビームの散乱イオンが透過電子検出器 30 側に入り、正確な透過ビーム電流値が測定しにくい。ため、透過電子検出器 30 側の断面の加工領域を先に完了させ、集束イオンビームの散乱イオンが検出器 30 に入りにくい領域 82 の加工段階で透過ビーム電流量検出による加工部の厚さ評価や終了点検出を行うためである。

【0052】試料 41 の分析／観察希望部を中心に、図 2g に示すように、透過電子顕微鏡用メッシュ 80 に貼る。透過電子顕微鏡により試料 41 の観察分析を行う。以上、集束イオンビームによる加工について述べたが、加工部の膜厚や膜厚均一性の評価としてイオンミリング等の加工においても使用可能である。

【0053】

【発明の効果】請求項 1 記載の透過電子顕微鏡用断面試料作成用集束イオンビーム装置及び請求項 3、4 記載の透過電子顕微鏡用断面試料作成方法によれば、均一な厚さの観察断面を形成することができると共に加工の超過を防止することができる。これにより、加工部の厚さのばらつきが 50% 以下の精度で検出でき、これを加工段階で修正できるため、最終段階では加工部の厚さのばらつきを 50nm 以下にでき、加工領域内のほぼ全域で高分解能観察を行うことができる。断面試料作成において試料厚さが数値化して検出できるので、材料毎に条件出しを行えば、オペレータの熟練度に影響なく最適な厚さの透過電子顕微鏡試料作成が行える。

【0054】請求項 2 の透過電子顕微鏡用断面試料作成用集束イオンビーム装置によれば、イオンビーム及び電子ビームの照射により発生した 2 次電子が透過電子検出器に検出されて透過電子ビーム電流検出精度が劣化することを防止できる。また、集束イオンビーム照射中でも透過電子ビーム電流検出が可能となり、集束イオンビーム照射中でも加工の超過を防止することができる。これにより、断面試料の加工精度が向上できると共に、断面試料の作成を容易に行うことができる。

【図面の簡単な説明】

【図 1】本発明の透過電子顕微鏡用断面試料作成用集束イオンビーム装置の実施例を示す概略構成図である。

【図 2a】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 2b】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 2c】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 2d】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 2e】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 2f】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 2g】本発明の透過電子顕微鏡用断面試料作成方法

の実施例を示す図である。

【図 3a】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3b】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3c】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3d】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3e】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3f】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3g】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 3h】本発明の透過電子顕微鏡用断面試料作成方法の実施例を示す図である。

【図 4a】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 4b】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 4c】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 4d】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 4e】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 4f】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 4g】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5a】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5b】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5c】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5d】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5e】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5f】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 5g】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【図 6】従来の透過電子顕微鏡用断面試料作成方法を示す図である。

【符号の説明】

10 イオン銃

20 電子銃

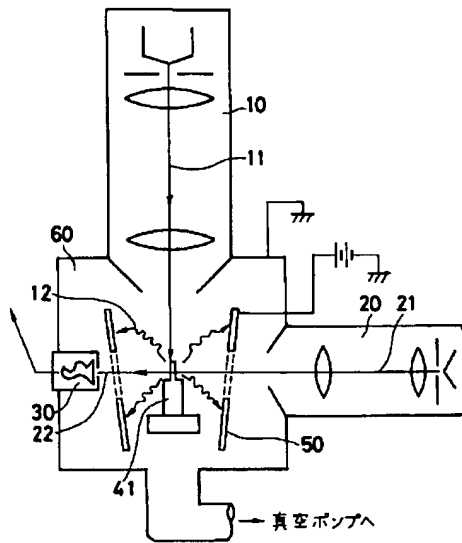
30 透過電子検出器

40 試料

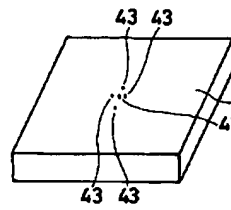
* 50 低電圧電極

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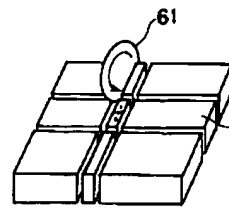
【図1】



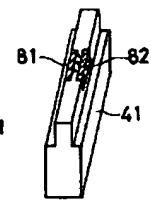
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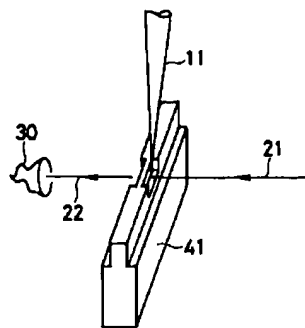
【図2 b】



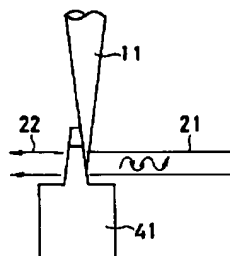
【図2 e】



【図2 f】

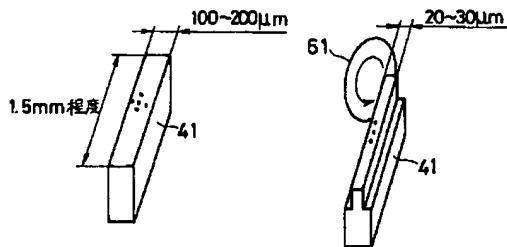


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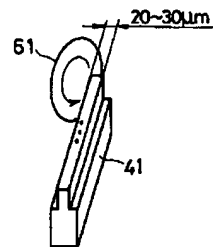


【図2 c】

【図2 d】

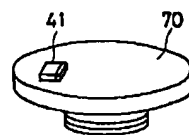


【図2 g】



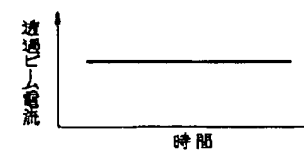
【図3 a】

【図4 d】

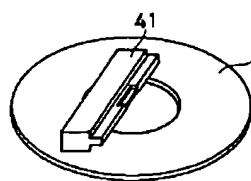
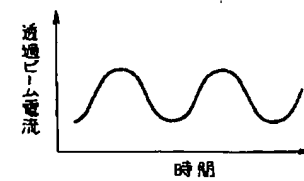


【図3 b】

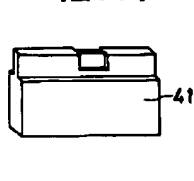
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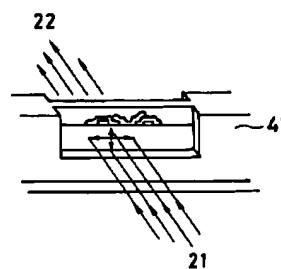
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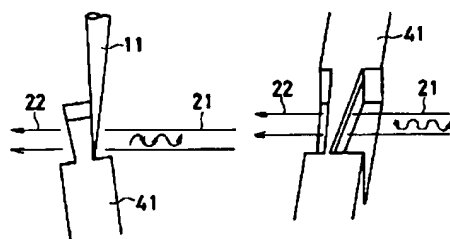
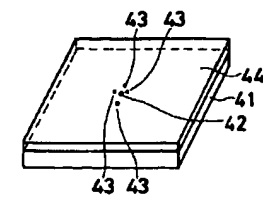
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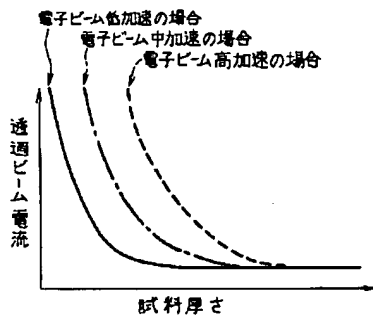
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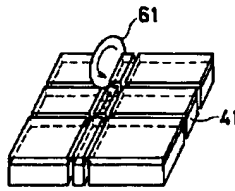
【図4 a】



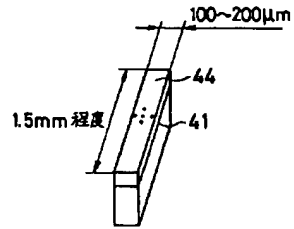
【図3h】



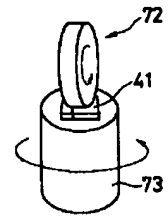
【図4b】



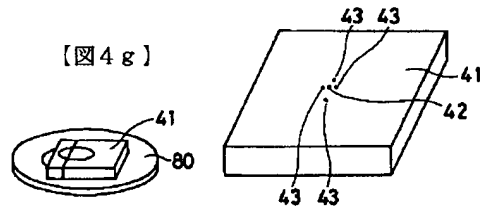
【図4c】



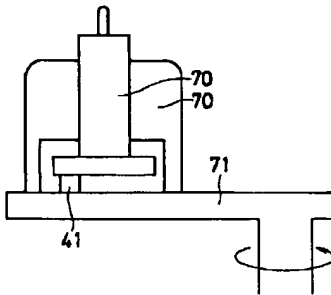
【図4f】



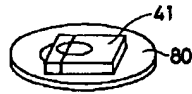
【図5a】



【図4e】



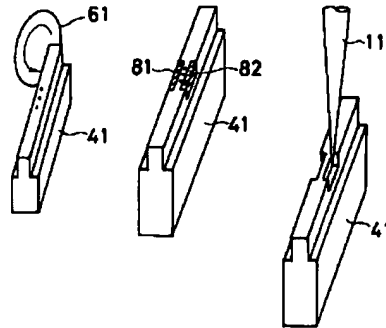
【図4g】



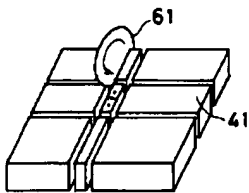
【図5d】

【図5e】

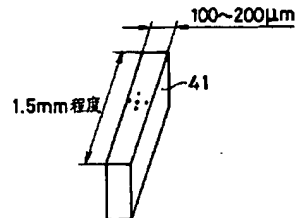
【図5f】



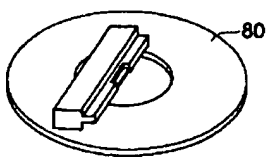
【図5b】



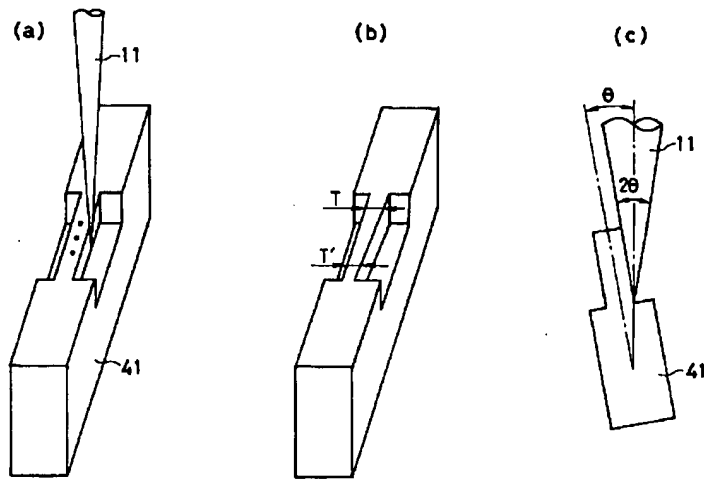
【図5c】



【図5g】



【図 6】



フロントページの続き

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H 0 1 J 37/31

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37/28	Z			
37/30	Z	9172-5E		
			G 01 N 1/28	F
Request for Examination: Not requested		Number of Claims: 4	OL	(10 pages total)
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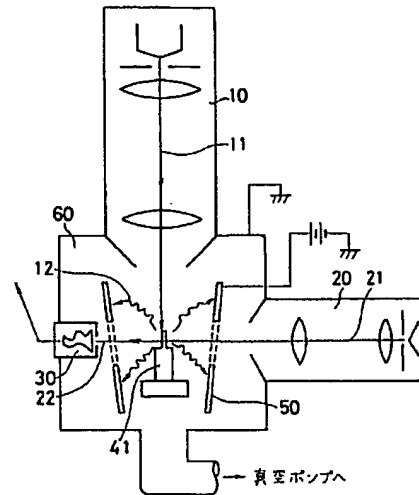
(21) Application Number: H6-141852	(71) Applicant: 000005049 Sharp Corporation 22-22 Nagaike-cho, Abeno-ku, Osaka-shi, Osaka
(22) Filing Date: June 23, 1994	(72) Creator: Fumitoshi Yasuo c/o Sharp Corporation 22-22 Nagaike-cho, Abeno-ku, Osaka-shi, Osaka
	(74) Agent: Yoshio Kawaguchi, Patent Attorney (and one other)

(54) [Title of the Invention] **FOCUSED ION BEAM APPARATUS FOR PRODUCING CROSS-SECTIONAL SAMPLE FOR TRANSMISSION ELECTRON MICROSCOPE AND METHOD FOR PRODUCING CROSS-SECTIONAL SAMPLE FOR TRANSMISSION ELECTRON MICROSCOPE**

(57) [Abstract]

[Object] [The object of the present invention is] to provide a focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope which makes it possible to automatically detect the working endpoint at the optimal sample thickness by quantitatively monitoring the thickness of the worked surface of the transmission electron microscope sample, and which also allows easy judgement of the uniformity of the thickness of the worked part during working, and a method for producing such a sample.

[Constitution] [The apparatus of the present invention] comprises a working chamber 60 in which a cross-sectional sample 41 for a transmission electron microscope is disposed, an ion gun 10 which emits an ion beam 11 onto the sample 41 disposed in the working chamber 60, an electron gun 20 which irradiates the worked portion of the sample 41 with an electron beam 21 at an angle of approximately 90 degrees with respect to the ion beam 11 emitted by the ion gun 10, a transmission electron detector 30 which is disposed facing the above-mentioned electron gun 20, and which receives the electron beam that is transmitted through the sample 41 and detects the amount of current of the transmitted electron beam, and a low-voltage electrode 50 which is positioned so that this electrode surrounds the sample 41 in the vicinity of the position where the above-mentioned sample 41 is fixed, and which absorbs the secondary electrons 12 generated by the ion beam 11 and electron beam 12.



[Key:] To vacuum pump

[Claims]

[Claim 1] A focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope, comprising ion gun means which emit an ion beam that is used to produce a cross-sectional sample for a transmission electron microscope, electron gun means which irradiate the worked portion of the above-mentioned cross-sectional sample for a transmission electron microscope with an electron beam at an angle of approximately 60 to 90 degrees with respect to the ion beam emitted by the above-mentioned ion gun means, and detection means which are disposed facing the above-mentioned electron gun means, and which receive the electron beam that is transmitted through the above-mentioned cross-sectional sample for a transmission electron microscope, and detect the amount of current of the transmitted electron beam.

[Claim 2] The focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope according to Claim 1, which comprises electrode means that absorb the secondary electrons generated by the irradiation with the ion beam and electron beam in the vicinity of the position where the above-mentioned cross-sectional sample for a transmission electron microscope is fixed.

[Claim 3] A method for producing a cross-sectional sample for a transmission electron microscope comprising the steps of cutting a sample requiring cross-sectional observation by a transmission electron microscope to a thickness that allows mounting in such a transmission electron microscope, making the observation region even thinner by means of an ion beam, irradiating the worked part of the above-mentioned sample with an electron beam while [the sample is] being made thinner by means of the above-mentioned ion beam, detecting the amount of current of the electron beam that is transmitted through the above-mentioned sample, and evaluating the uniformity of the thickness of the worked part of the above-mentioned sample on the basis of the above-mentioned detected current amount by scanning this worked part with the above-mentioned electron beam.

[Claim 4] A method for producing a cross-sectional sample for a transmission electron microscope comprising the steps of cutting a sample requiring cross-sectional observation by a transmission electron microscope to a thickness that allows mounting in such a transmission electron microscope, making the observation region even thinner by means of an ion beam, irradiating the worked part of the above-mentioned sample with an electron beam while [the sample is] being made thinner by means of the above-mentioned ion beam, detecting the amount of current of the electron beam that is transmitted through the above-mentioned sample, and

detecting the working endpoint of the above-mentioned sample on the basis of the above-mentioned detected current amount.

[Detailed Description of the Invention]

[0001]

[Field of Industrial Utilization] The present invention relates to a focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope and a method for producing a cross-sectional sample for a transmission electron microscope, and more particularly relates to a focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope and a method for producing a cross-sectional sample for a transmission electron microscope which produce a cross-sectional sample (for a transmission electron microscope) of a specified microscopic part such as the location of a defect on an LSI chip.

[0002]

[Prior Art] Recently, as LSI devices have become finer and films of LSI materials have become thinner, the observation and evaluation of fine structures that determine LSI device performance have become extremely important. In particular, extremely thin films with thicknesses of a few nanometers have been used as gate insulating films of transistors, and a high spatial resolution with a few tenths of a nanometer or less is considered necessary for the observation and evaluation of such fine structures. Furthermore, the evaluation of crystal defects, which are a cause of leaks in the fine transistors of LSI devices, and which lead to various types of defects, is also extremely important for improving the performance and improving the yield of LSIs. A transmission electron microscope (TEM) is the only evaluation device that can achieve such objects.

[0003] A transmission electron microscope has the highest spatial resolution among high-resolution observation and evaluation devices, i.e., approximately 0.2 nm, and is the only means of observing and evaluating LSI gate insulating films, etc., that are formed as ultra-thin films. Furthermore, a transmission electron microscope is also the only device that can directly observe crystal defects with a high spatial resolution. Moreover, a transmission electron microscope is capable not only of observation, but also of elemental analysis at a spatial resolution of approximately 1 nm in combination with an X-ray microanalyzer (EPMA), etc., and has a spatial resolution that is approximately 1/20 that of the Auger electron spectroscopic analysis method (AES), which has the highest spatial resolution among other analysis methods. Accordingly, such a transmission electron microscope has the status of an extremely useful analysis tool in the analysis of LSI devices of progressively greater fineness.

[0004] A projected image of an electron beam that is transmitted through the sample is used in observation and evaluation performed by means of a transmission electron microscope.

Accordingly, samples used in a transmission electron microscope must be worked to a thickness that allows the transmission of such an electron beam. In concrete terms, it is necessary to form [the sample] into a thin film with a thickness of approximately 500 nm or less, and in order to perform high-resolution observations for the purpose of evaluating the crystal structure, etc., in particular, it is necessary to form the sample into a thin film with a thickness of approximately 100 nm or less.

[0005] Generally, the preparation of LSI samples for use in a transmission electron microscope is accomplished by performing the final thin film formation by means of an ion beam after the samples have been thinned by mechanical means. However, this technique is used in cases where thin films formed over a broad range, or arbitrary locations in an LSI pattern in which the same shape is repeated, are the object [of observation]. In cases where specified locations on finely worked LSIs, e.g., defective transistors or open contacts, are evaluated, there is a danger that the observation and evaluation location will be lost if the position of the worked part of thin film formation shifts. Accordingly, in the preparation of samples for a transmission electron microscope, it is necessary to form a specified location into a thin film with a positional precision of 1 μm or better. This cannot be accomplished using simple mechanical polishing and ion beam working. Accordingly, several sample working methods have been proposed.

[0006] Below, a method in which a transmission electron microscope sample used for transmission electron microscope observation and analysis of the cross sections of specified microscopic parts such as the locations of defects on LSI chips is worked by mechanical polishing will be described using Figures 4a through 4g.

[0007] (1-1) As is shown in Figure 4a, marking 43 is performed by forming holes around a specified microscopic part 42 for which transmission electron microscope observation is desired by means of a laser marker or focused ion beam apparatus, etc., equipped with a microscope. Furthermore, in order to protect the specified microscopic part 42 from the thermal effects of laser or ion beam irradiation or contamination by flying debris from the hole formation process used for marking 43, it is advisable to perform the marking in positions that are separated from the specified microscopic part 42 by a distance of approximately 20 μm or greater. From the standpoint of positional confirmation in subsequent working, it is desirable that the size and depth of the marking be as large as possible; on the other hand, from the standpoint of the need to suppress heat and flying debris during marking, it would appear desirable that the size [of the marking] be approximately 5 μm or less, and that the depth [of the marking] be approximately 1

to 5 μm . In cases where it is necessary to use a low-power microscope such as a stereoscopic microscope in the working of the sample, it is advisable to add marking with a size of approximately 10 μm to the above-mentioned marking in a position that is separated from the specified microscopic part 42 by a distance of 40 μm or greater.

[0008] (1-2) A glass 44 is pasted to the surface of the sample 41 in order to protect the surface.

[0009] (1-3) Using the marking as a reference, the area around the specified microscopic region for which observation or analysis is desired is cut by means of the high-speed outer circumferential rotary blade 61 of a dicing machine to a size of approximately 1.5 mm square or less, which allows introduction [of the sample] into a transmission electron microscope. In this case, as is shown in Figures 4b and 4c, [it is desirable to] select surfaces that are parallel to the sectional surface for which observation or analysis of the transmission electron microscope sample 41 is desired, and surfaces that are perpendicular to this surface, as the cut surfaces. In regard to the cutting width in the direction perpendicular to the sectional surface for which observation/analysis of the sample 41 is desired, a narrower width makes it possible to shorten the time required for the subsequent polishing; accordingly, cutting is performed at a narrow width within a range that causes no destruction of the specified microscopic part 42 (for which observation or analysis is desired) during cutting, e.g., 100 to 200 μm .

[0010] (1-4) As is shown in Figures 4d and 4e, the two cut surfaces parallel to the sectional surface for which observation or analysis of the sample 41 is desired are mechanically polished by means of a polishing tool 70 and a rotary polishing platen 71. In this case, using the marking as a reference, one side surface is polished until a distance of approximately 10 μm is reached with respect to the specified microscopic part 42 for which observation/analysis is desired. The other side surface that is opposite this first side surface of the sample 41 is polished until a distance of approximately 70 μm is reached with respect to the specified microscopic part 42. As a result, the width of the sample 41, which is the interval between the polished surfaces, is approximately 80 μm . Furthermore, polishing grains with a size of approximately 5 to 15 μm , which have a relatively rapid polishing speed, are used for the polishing up to this point. The polished surface on the first side surface of the sample 41, which is close to the specified microscopic part 42, is subjected to mirror finishing using even finer polishing grains with a size of 1 μm or less in this stage.

[0011] (1-5) As is shown in Figure 4f, the sample 41 is fastened to the surface of a rotating stage 73 with the polished surface that has not been subjected to mirror finishing, i.e., the second side surface of the sample 41 which is distant from the specified microscopic part 42, facing upward, and is subjected to dimple grinder polishing centered on the portion for which

observation/analysis is desired by means of a rotary polishing disk 72. In this dimple grinder polishing, polishing is first performed using a polishing material with a size of 5 to 10 μm until the thickness in the vicinity of the portion for which observation/analysis is desired reaches 20 to 30 μm . Then, mirror finishing of the portion for which observation/analysis is desired is performed using polishing grains with a size of 1 μm or less.

[0012] (1-6) As is shown in Figure 4g, [the sample 41] is pasted to a transmission electron microscope mesh 80 with the portion of the sample 41 for which analysis/observation is desired at the center.

[0013] (1-7) Ion milling is performed on both sides using an ion milling device so that a thickness of 500 nm or less is obtained.

[0014] (1-8) Observation and analysis of the sample 41 are performed by means of a transmission electron microscope.

[0015] Next, a transmission electron microscope sample working method using a focused ion beam apparatus disclosed in Japanese Patent Application Kokai No. H2-132345 and Japanese Patent Application Kokai No. H5-180739 will be described with reference to Figures 5a through 5g.

[0016] (2-1) As is shown in Figures 5a through 5c, marking is performed on the sample, and cutting of the sample 41 is performed by the same methods as in the above-mentioned (1-1) and (1-3). If necessary, the region of the sample for which observation/analysis is desired is ground even thinner by means of the high-speed outer circumferential rotary blade 61 of a dicing machine as shown in Figure 5d.

[0017] (2-2) As is shown in Figures 5e and 5f, the area in the vicinity of the specified microscopic part 42 for which observation/analysis is desired is irradiated from the direction of the sample surface with a focused ion beam 11 by means of a focused ion beam apparatus. In this case, as is shown in Figure 5g, the focused ion beam 11 is raster-scanned over rectangular regions 81 and 82 that have one side parallel to the sectional surface for which observation/analysis is desired, and these regions are etched by sputtering. The raster scanning regions are gradually caused to approach the sectional surface for which observation/analysis is desired while the beam current and beam diameter, etc., of the focused ion beam 11 are appropriately selected, so that sectional surface working is performed as shown in Figure 5f. The specified microscopic part 42 for which observation/analysis is desired is formed into a thin film by performing this working from both sides of this microscopic part, thus producing a transmission electron microscope sample.

[0018] Furthermore, as is shown in Figure 6 (c), if the focused ion beam 11 has an inverted circular conical shape, and beam irradiation is performed perpendicular to the sample surface, a perpendicular sectional surface cannot be obtained. Accordingly, a perpendicular sectional surface is obtained by inclining the sample 41 by a specified angle of θ . Since this angle θ varies according to the focused ion beam apparatus and working conditions, conditions must be determined in advance, and working is generally performed at an inclination of approximately 3 to 5 degrees. Furthermore, during actual working, the working process is intermittently interrupted, the worked shape is evaluated through the observation of a secondary ion image or secondary electron image obtained by means of the focused ion beam, observation with the sample transferred to a scanning electron microscope, or observation of a secondary electron image produced by irradiation with an electron beam inside the apparatus (in the case of a focused ion beam apparatus which has an electron beam irradiation function), etc., and in cases where there is a problem, adjustment of the focused ion beam, alteration of the conditions, or adjustment of the angle of the sample, is appropriately performed.

[0019] (2-3) With the portion of the sample 41 for which analysis/observation is desired placed at the center, [the sample] is pasted to a transmission electron microscope mesh 80 as shown in Figure 5g.

[0020] (2-4) The sample 41 is observed and analyzed by means of the transmission electron microscope.

[0021] The endpoint of focused ion beam working [may be] determined by the following methods:

[0022] (1) The shape of the worked part is observed using a secondary ion image or secondary electron image, etc., obtained by ion beam irradiation, and the working endpoint is determined by judging the thickness of the worked part from the observed image. Furthermore, the image resolution is several tens of nanometers.

[0023] (2) Focused ion beam working and scanning electron microscopic observation are alternately performed, and the working endpoint is determined by judging the thickness of the worked part from the image of the worked part observed by means of the scanning electron microscope. Alternatively, focused ion beam working and scanning electron microscopic observation are alternately performed, and the degree of completion of the sample is judged from the resolution of the transmission electron microscopic observation.

[0024] (3) As is disclosed in Japanese Patent Application Kokai No. H4-76437, in a focused ion beam apparatus which is equipped with an electron gun separately from the ion gun, or in a

focused ion beam apparatus which can perform electron beam irradiation using the ion gun, focused ion beam working and observation by means of an electron beam are alternately performed within the focused ion beam apparatus, and the working endpoint is determined by judging the thickness of the worked part from the observed image.

[0025]

[Problems that the Invention is to Solve] In the case of conventional methods for working a transmission electron microscope sample by means of mechanical polishing, the precision of the working position with respect to the microscopic part for which observation and evaluation are desired is a few microns in the mechanical polishing stage. Accordingly, the precision of 1 μm or better that is required in working for the purpose of observing the locations of defects in LSIs cannot be obtained.

[0026] In the case of conventional methods for working a transmission electron microscope sample by means of a focused ion beam apparatus, when the worked shape is evaluated through the observation of a secondary ion image or secondary electron image created by a focused ion beam, or when the working endpoint is judged by evaluating the thickness of the worked surface through the observation of a secondary ion image or secondary electron image created by a focused ion beam, the target thickness of working is several tens to several hundreds of nanometers. However, the beam system [sic]^{*} of the focused ion beam is at least approximately 100 nm, and since the resolution of the secondary ion image or secondary electron image that is obtained also depends on the ion beam diameter, it is difficult to judge the accurate thickness on the screen, so that the success rate of sample preparation drops. Since observation and working by means of the focused ion beam are alternately performed, there is a danger that working will be performed beyond the working endpoint. In order to perform sectional working with a focused ion beam having an inverted circular conical shape, the sample is inclined and worked as shown in Figure 6 (c); however, because of variation in the adjustment of the focused ion beam, etc., the sectional surface that is worked deviates from a plane perpendicular to the surface [of the sample] with each working. For example, in a case where the angle of inclination of both worked surfaces is 2 degrees, the thickness at a position located at a depth of 3 μm shows a deviation of 100 nm with respect to the width of various parts of the outermost surface. Under such conditions, in cases where the width of the worked part reaches the target of 100 nm at the outermost surface 9 [sic][†], a width of 200 nm or 0 nm is obtained at a depth of 3 μm , depending

^{*} Translator's note: apparent word processing error in the original for "beam diameter"; the terms "system" and "diameter" are homophonous in Japanese.

[†] Translator's note: Nothing in the figures is designated with "9."

on the direction of the inclination, so that a hole is formed. A depth of 3 μm corresponds to the thickness of an LSI device structure from the surface. Furthermore, in cases where the width of the worked part is 200 nm, high-resolution observation such as lattice image observation is difficult. Such an error in the angle of the worked surface with respect to the vertical direction is impossible to evaluate by observation at the observation resolution of the focused ion beam, especially from above, so that the respective thicknesses of the parts for which observation and evaluation are desired cannot be accurately evaluated; accordingly, the success rate of transmission electron microscope sample preparation drops.

[0027] In cases where the worked shape or working endpoint obtained by a focused ion beam is judged using a scanning electron microscope, or in cases where this judgment is made based on the observed image by means of a transmission electron microscope, focused ion beam working and electron microscopic observation are alternately performed; accordingly, time is required for switching of the sample, etc., so that the working time is prolonged. While the working time is generally 3 to 5 hours, if observation is added, a minimum time of approximately 1 hour per observation is required for sample replacement, observation and focused ion beam readjustment, so that even if observation that is performed only two or three times is added, the required time from start to finish of the focused ion beam working is increased by a factor of 1.5 to 2. In cases where focused ion beam working and electron microscopic observation are alternately performed, error in the working direction is generated by the replacement of the sample as shown in Figures 6 (a) and 6 (b) when working is again performed using the focused ion beam. As a result, the thickness of the observed part becomes non-uniform, so that good observation is difficult. In an electron microscope, the observation resolution is a few nanometers or better, so that the thickness of the surface of the observed part can be evaluated more accurately than in the case of an observation method using an ion beam. However, it is difficult to observe and evaluate the worked shape, e.g., to evaluate the angular error of the worked surface with respect to the vertical direction by observation from above, so that the accurate film thickness of the part for which observation is desired cannot be evaluated. When focused ion beam working is again performed following observation, the focused ion beam must be readjusted, and the conditions vary, so that feedback from the evaluation results is also impossible.

[0028] In cases where the judgement of the endpoint of focused ion beam working is accomplished by the observation of a secondary electron image, etc., obtained by means of an electron beam in a focused ion beam apparatus equipped with an electron beam irradiation function, secondary electron image observation by means of an electron beam cannot be performed during focused ion beam working because of the secondary electrons that are generated by ion beam irradiation even in cases where the apparatus has an electron gun that is

separate from the ion gun, to say nothing of cases where the ion gun is also used as an electron gun. Accordingly, working and observation cannot be performed at the same time, and there is a danger that working will be performed beyond the working endpoint. Since the worked part is observed from above, the inclination of the worked surface with respect to the vertical direction cannot be accurately evaluated.

[0029] The present invention was devised in order to eliminate the above-mentioned problems. The object of the present invention is to provide a focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope and a method for producing a cross-sectional sample for a transmission electron microscope which make it possible to automatically detect the optimal sample thickness by quantitatively monitoring the thickness of the worked surface of the transmission electron microscope sample, and which also allow easy judgement of the uniformity of the thickness of the worked part during working.

[0030]

[Means for Solving the Problems] In the present invention, the above-mentioned object is achieved by the focused ion beam apparatus of Claim 1 for producing a cross-sectional sample for a transmission electron microscope, which comprises ion gun means which emit an ion beam that is used to produce a cross-sectional sample for a transmission electron microscope, electron gun means which irradiate the worked portion of the above-mentioned cross-sectional sample for a transmission electron microscope with an electron beam at an angle of approximately 60 to 90 degrees with respect to the ion beam emitted by the above-mentioned ion gun means, and detection means which are disposed facing the above-mentioned electron gun means, and which receive the electron beam that is transmitted through the above-mentioned cross-sectional sample for a transmission electron microscope, and detect the amount of current of the transmitted electron beam.

[0031] In the present invention, the above-mentioned object is achieved by the focused ion beam apparatus of Claim 2 for producing a cross-sectional sample for a transmission electron microscope, which comprises electrode means that absorb the secondary electrons generated by the irradiation with the ion beam and electron beam in the vicinity of the position where the above-mentioned cross-sectional sample for a transmission electron microscope is fixed.

[0032] In the present invention, the above-mentioned object is achieved by the method of Claim 3 for producing a cross-sectional sample for a transmission electron microscope, which comprises the steps of cutting a sample requiring cross-sectional observation by a transmission electron microscope to a thickness that allows mounting in such a transmission electron

microscope, making the observation region even thinner by means of a focused ion beam, irradiating the worked part of the sample with an electron beam while [the sample is] being made thinner by means of the focused ion beam, detecting the amount of current of the electron beam that is transmitted through the sample, and evaluating the uniformity of the thickness of the worked part of the sample on the basis of the above-mentioned detected current amount by scanning this worked part with the electron beam.

[0033] In the present invention, the above-mentioned object is achieved by the method of Claim 4 for producing a cross-sectional sample for a transmission electron microscope, which comprises the steps of cutting a sample requiring cross-sectional observation by a transmission electron microscope to a thickness that allows mounting in such a transmission electron microscope, making the observation region even thinner by means of a focused ion beam, irradiating the worked part of the sample with an electron beam while [the sample is] being made thinner by means of the focused ion beam, detecting the amount of current of the electron beam that is transmitted through the sample, and detecting the working endpoint of the sample on the basis of the above-mentioned detected current amount.

[0034]

[Operation] In the focused ion beam apparatus of Claim 1 for producing a cross-sectional sample for a transmission electron microscope, the sample surface is irradiated with a focused ion beam by the ion gun means at an arbitrary acceleration voltage, beam current and beam diameter, and an arbitrary region on the sample surface is raster-scanned. During ion beam working, the sample is irradiated in an arbitrary position on the worked surface with an electron beam at an angle of approximately 60 degrees to 90 degrees with respect to the ion beam, and at an arbitrary acceleration voltage, beam current and beam diameter, by the electron gun means. Furthermore, the electron beam that passes through the sample is received by the detection means, the amount of current of the transmitted electron beam is detected by the detection means, and working by means of the focused ion beam is ended at a stage in which the current value of the transmitted beam reaches a preset value.

[0035] In the focused ion beam apparatus of Claim 2 for producing a cross-sectional sample for a transmission electron microscope, electrons such as the secondary electrons created by the focused ion beam that irradiates the sample are absorbed by electrode means to which an arbitrary positive voltage is applied, so that [such electrons] do not reach the detection means and interfere with the detection of the amount of the transmission electron beam current.

[0036] In the method of Claim 3 for producing a cross-sectional sample for a transmission electron microscope, when a cross-sectional sample for a transmission electron microscope is to be prepared, the sample requiring cross-sectional observation by means of a transmission electron microscope is cut to a thickness that allows mounting in the transmission electron microscope, the observation region is further thinned by means of the focused ion beam, the worked part is irradiated with an electron beam while being formed into a thin film by means of the focused ion beam, the amount of current of the transmitted beam is detected, the uniformity of the thickness of the worked part of the above-mentioned sample is evaluated on the basis of the detected current value, and a cross-sectional sample for a transmission electron microscope which has a uniform thickness is prepared on the basis of this evaluation.

[0037] In the method of Claim 4 for producing a cross-sectional sample for a transmission electron microscope, when a cross-sectional sample for a transmission electron microscope is to be prepared, such a cross-sectional sample for a transmission electron microscope is prepared by a process in which the sample requiring cross-sectional observation by means of a transmission electron microscope is cut to a thickness that allows mounting in the transmission electron microscope, the observation region is further thinned by means of the focused ion beam, the worked part is irradiated with an electron beam while being formed into a thin film by means of the focused ion beam, the electron beam passing through the sample is monitored, and the working endpoint is detected.

[0038]

[Embodiments] Below, an embodiment of the focused ion beam apparatus of Claim 1 for producing a cross-sectional sample for a transmission electron microscope will be described with reference to Figure 1. The object of the present embodiment is to provide a focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope which can automatically detect the optimal sample thickness by quantitatively monitoring the thickness of the worked surface of the transmission electron microscope sample, and which can easily judge the uniformity of the thickness of the worked part during working.

[0039] The present embodiment comprises a working chamber 60 in which the cross-sectional sample 41 for a transmission electron microscope is disposed, an ion gun 10 used as ion gun means for emitting an ion beam 11 onto the sample 41 disposed in the working chamber 60, an electron gun 20 used as electron gun means for irradiating the worked part of the sample 41 with an electron beam 21 at an angle of approximately 90 degrees with respect to the ion beam 11 emitted by the ion gun 10, a transmission electron detector 30 used as detection means which are disposed facing the above-mentioned electron gun 20, and which receive the electron beam that

passes through the above-mentioned cross-sectional sample 41 for a transmission electron microscope, and detect the amount of current of the transmitted electron beam, and a low-voltage electrode 50 used as electrode means which are disposed so as to surround the above-mentioned sample 41 in the vicinity of the position where this sample 41 is fixed, and which absorb the secondary electrons 12 that are generated by the ion beam 11 and electron beam 21, and thus prevent the occurrence of a situation in which the accurate amount of current of the transmitted beam cannot be measured.

[0040] [The system] is constructed so that the sample 41 is conveyed into the interior of the working chamber 60 by a sample introduction system (not shown in the figures), and is appropriately driven by a stage driving system (not shown in the figures). The ion beam 11 and electron beam 12 are respectively capable of raster scanning, and [the system is] constructed so that observation of the shapes of the respective beam irradiation regions can be accomplished by a secondary ion detector or secondary electron detector (not shown in the figures). Furthermore, the operation of the present embodiment is the same as that of the embodiment of the method for producing a cross-sectional sample for a transmission electron microscope that will be described later; accordingly, a description of this operation is omitted.

[0041] Next, embodiments of the methods of Claims 3 and 4 for producing a cross-sectional sample for a transmission electron microscope will be described with reference to Figures 2a through 2g and Figures 3a through 3h. The object of the present embodiments is to provide a method for producing a cross-sectional sample for a transmission electron microscope which can automatically detect the optimal sample thickness by quantitatively monitoring the thickness of the worked surface of the transmission electron microscope sample, and which can easily judge the uniformity of the thickness of the worked part during working.

[0042] As is shown in Figure 2a, marking 43 is performed by forming holes by means of the focused ion beam apparatus or a laser marker that is equipped with a microscope, etc., around a specified microscopic part 42 for which cross-sectional observation/analysis by means of a transmission electron microscope is desired (such as a defective transistor on an LSI chip 41). Furthermore, it is advisable that this marking be performed in a position that is separated from the specified microscopic part 42 by a distance of approximately 20 μm or greater in order to prevent the specified microscopic part 42 from being subjected to the thermal effects of the laser or ion beam irradiation used for marking 43 or contamination by flying debris from the formation of the holes. From the standpoint of positional confirmation in subsequent working, it is desirable that the size and depth of the marking be as large as possible; on the other hand, from the standpoint of the need to suppress heat and flying debris during marking, it is advisable that

the size [of the marking] be approximately 5 μm or less, and that the depth [of the marking] be approximately 1 to 5 μm . Using the marking as a reference, the area around the specified microscopic region for which observation or analysis is desired is cut to a size of approximately 1.5 mm square or less, which allows introduction into the transmission electron microscope, by means of the high-speed outer circumferential rotary blade 61 of a dicing machine.

[0043] In this case, as is shown in Figure 2b, surfaces that are parallel to the sectional surface of the transmission electron microscope sample 41 for which observation or analysis is desired are selected as the cut surfaces. In regard to the cutting width in the direction perpendicular to the sectional surface of the sample 41 for which observation/analysis is desired, a narrower cutting width allows a reduction in the subsequent focused ion beam working range; accordingly, cutting is performed so that the cutting width in the perpendicular direction is narrow within a range that causes no destruction such as chipping of the specified microscopic part 42 (for which observation/analysis is desired) during cutting, e.g., a width of 100 to 200 μm . If necessary, the area in the vicinity of the surface of the part of the sample for which observation/analysis is desired is ground even thinner by the high-speed outer circumferential rotary blade 61 of the dicing machine as shown in Figure 2d.

[0044] The worked LSI chip is introduced into the focused ion beam apparatus. When the LSI chip is introduced into the focused ion beam apparatus, the orientation of the LSI chip is set so that the worked sectional surface faces the electron gun 20 inside the focused ion beam apparatus. The rectangular regions 81 and 82 which have the sectional surface for which observation/analysis is desired as one side are irradiated with the focused ion beam 11 in a raster scan by means of the focused ion beam apparatus, thus performing thin film working of the sectional surface for which observation/analysis is desired. The rectangular region 81 faces the transmission electron detector 30, and the rectangular region 82 is a region that includes a sectional surface facing the electron gun 20 inside the focused ion beam apparatus. In this focused ion beam working, the working of the region 81 is performed first. In the working of the region 81, the positional precision of the working of the sectional surface and the uniformity of the worked surface are increased while lowering the beam current/beam diameter of the focused ion beam 11 in steps.

[0045] The general working conditions are as follows: specifically, working is performed to a position that is separated from the specified microscopic part 42 constituting the target by a distance of a few microns using a Ga ion beam at an acceleration voltage of 25 to 30 kV and a beam current of approximately 2000 pA; then, working is performed to a position that is separated from the specified microscopic part 42 by a distance of 1 μm at a beam current of

approximately 400 pA. Furthermore, working is then performed to a position that includes the specified microscopic part 42 at a beam current of approximately 100 pA, and finally, the finishing of the worked surface is performed using a beam that has a beam current of a few tens of picoamperes. Furthermore, the focused ion beam 11 has an inverted circular conical shape, so that if beam irradiation is performed perpendicular to the sample surface, a vertical sectional surface cannot be obtained; accordingly, working is performed with the sample 41 inclined at an angle of approximately 3 to 5 degrees in accordance with the beam conditions.

[0046] Following the completion of the working of the region 81, the working of the region 82 is performed by the same method. In the working of the region 82, irradiation with the electron beam 21 is performed substantially perpendicular to the sectional surface for which observation/analysis is desired in the stage where the thickness of the worked part has reached approximately 1 μm , and the transmission electrons passing through the worked part of the sectional surface of the sample are detected by the transmission electron detector 30.

[0047] The acceleration voltage of the electron beam is set at 10 kV or greater. In the case of silicon, the electron beam will pass through a thickness of 1 μm if the acceleration voltage is 10 kV or greater. Accordingly, as a result of this electron beam irradiation, the transmission electrons are detected by the detector 30. Furthermore, a Channeltron, etc., which has a high sensitivity and a rapid detection rate is effective as the detector 30. However, depending on the material of the sample and the setting of the electron beam current, a Faraday cup, etc., may also be used. The voltage that is applied to the detector 30 and the current of the electron beam are appropriately set in accordance with the transmission electron beam current that is detected. The electron beam can be manipulated upward and downward and to the left and right within the range of the same material as shown in Figures 3a and 3b, and when the transmission beam current is detected during this period, a uniform waveform will be obtained as shown in Figure 3c in cases where the thickness of the worked part is uniform. On the other hand, in cases where the thickness of the worked part is non-uniform as shown in Figures 3e, 3f and 3g, the transmission beam current waveform will be a waveform such as that shown in Figure 3d. The non-uniformity of the worked part confirmed in this stage can be finally corrected by correcting the focused ion beam shape and sample angle, etc., in subsequent working.

[0048] The working of the region 82 is performed by focused ion beam working while continuing the detection of the transmission beam current. As the thickness of the worked part becomes smaller, the transmission beam current increases. If the acceleration voltage of the electron beam 21 is lowered in steps in accordance with the increase in the detected transmission beam current, then the thickness through which the electron beam is transmitted also drops as

shown in Figure 3h. Accordingly, if the acceleration voltage is appropriately selected, the variation in the thickness of the worked part can be accurately detected in accordance with the variation in the transmission beam current. In the case of a silicon material, if the acceleration voltage of the final electron beam 21 is set at approximately 3 kV or less, thicknesses of approximately 500 to 1000 Å can be detected by the value of the transmission beam current. If the conditions of the amount of the transmission current are determined using a good transmission electron microscope sample, and the transmission beam current amount taken as the working endpoint is determined in advance, then the working endpoint can be automatically detected.

[0049] Furthermore, in this detection of the transmission electron beam, a deterioration in the precision of detection of the transmission electron beam current can be prevented by applying a low positive potential to the low-voltage electrode 50, and recovering large quantities of second electrons 12 generated by the irradiation with the focused ion beam. Thus, detection of the transmission electron beam current can be accomplished even during focused ion beam irradiation, so that excessive working can be prevented.

[0050] Furthermore, in order to prevent deleterious effects on the ion beam and electron beam, magnetization is prevented by using a nonmagnetic metal as the material of the low-voltage electrode 50. The voltage applied to the low-voltage electrode 50 is set at + several tens of volts so that this voltage will have no effect on the track of the focused ion beam or electron beam with [an acceleration voltage of] a few kilovolts to approximately 30 kV, and so that the recovery rate of the secondary electrons (with a voltage of several tens of electron-volts) generated by the focused ion beam irradiation is increased.

[0051] The reason that the region 81 is worked first is as follows: specifically, under conditions in which the working region 81 on the side of the sectional surface facing the transmission electron detector 30 is irradiated with the focused ion beam 11, scattered ions of the focused ion beam enter the side of the transmission electron detector 30, so that accurate measurement of the transmission beam current value becomes difficult. Accordingly, thickness evaluation and endpoint detection for the worked part by the detection of the transmission beam current amount in the stage of the working of the region 82, in which scattered ions of the focused ion beam tend not to enter the detector 30 are performed after first completing [the working of] the working region of the sectional surface on the side of the transmission electron detector 30.

[0052] As is shown in Figure 2g, [the sample 41] is pasted to the transmission electron microscope mesh 80 with the portion of the sample 41 for which analysis/observation is desired at the center. Then, observation and analysis of the sample 41 are performed by means of the

transmission electron microscope. The above has been a description of working by means of a focused ion beam; however, in regard to the evaluation of the film thickness of the worked part and uniformity of the film thickness, [this technique] can also be applied to working such as ion milling.

[0053]

[Effect of the Invention] In the focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope according to Claim 1, and the methods for producing a cross-sectional sample for a transmission electron microscope according to Claims 3 and 4, a sectional surface for observation which has a uniform thickness can be formed, and excessive working can be prevented. As a result, detection can be performed with a precision in which the variation in the thickness of the worked part is 50% [*sic*] or less, and this can be corrected in the working stage. Accordingly, the variation in the thickness of the worked part can be reduced to 50 nm or less in the final stage, so that high-resolution observations can be performed throughout more or less the entire region within the worked area. Since the sample thickness can be detected as a numerical value in the preparation of cross-sectional samples, transmission electron microscope samples with an optimal thickness can be prepared regardless of the degree of experience of the operator if the conditions are determined for each material.

[0054] In the focused ion beam apparatus for producing a cross-sectional sample for a transmission electron microscope according to Claim 2, it is possible to prevent the deterioration of the precision with which the transmission electron beam current is detected as a result of the detection by the transmission electron detector of secondary electrons generated by the ion beam and electron beam irradiation. Furthermore, detection of the transmission electron beam current is possible even during focused ion beam irradiation, so that excessive working can be prevented even during focused ion beam irradiation. As a result, the working precision of the cross-sectional sample can be improved, and the preparation of cross-sectional samples can easily be performed.

[Brief Description of the Drawings]

[Figure 1] Figure 1 is a schematic structural diagram which shows an embodiment of the focused ion beam apparatus of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2a] Figure 2a is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2b] Figure 2b is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2c] Figure 2c is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2d] Figure 2d is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2e] Figure 2e is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2f] Figure 2f is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 2g] Figure 2g is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3a] Figure 3a is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3b] Figure 3b is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3c] Figure 3c is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3d] Figure 3d is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3e] Figure 3e is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3f] Figure 3f is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3g] Figure 3g is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 3h] Figure 3h is a diagram which illustrates an embodiment of the method of the present invention for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4a] Figure 4a is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4b] Figure 4b is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4c] Figure 4c is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4d] Figure 4d is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4e] Figure 4e is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4f] Figure 4f is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 4g] Figure 4g is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 5a] Figure 5a is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 5b] Figure 5b is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 5c] Figure 5c is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 5d] Figure 5d is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 5e] Figure 5e is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

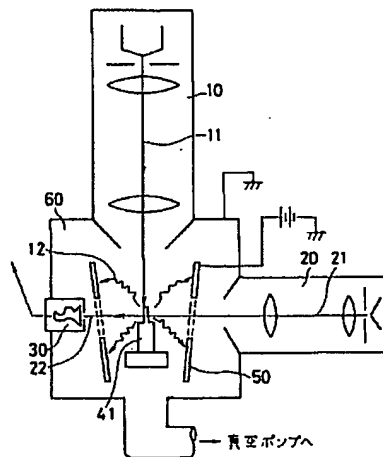
[Figure 5f] Figure 5f is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 5g] Figure 5g is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

[Figure 6] Figure 6 is a diagram which illustrates a conventional method for producing a cross-sectional sample for a transmission electron microscope.

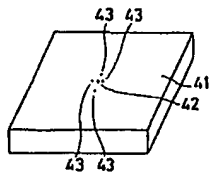
[Explanation of Symbols]

- 10: Ion gun
- 20: Electron gun
- 30: Transmission electron detector
- 40 [sic][†]: Sample
- 50: Low-voltage electrode

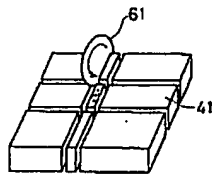


[Figure 1]

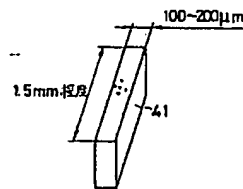
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[Figure 2a]

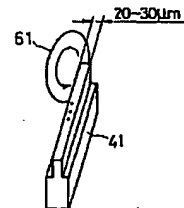


[Figure 2b]



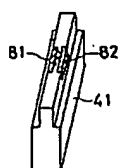
[Figure 2c]

[Key:] Approximately 1.5 mm

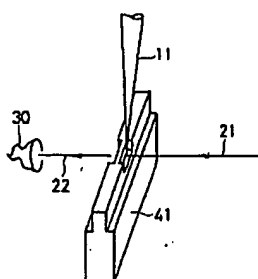


[Figure 2d]

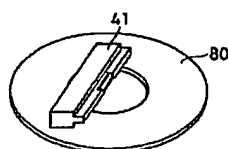
[†] Translator's note: apparent error in the original for "41."



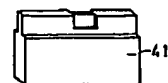
[Figure 2e]



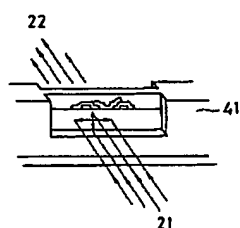
[Figure 2f]



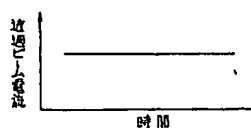
[Figure 2g]



[Figure 3a]

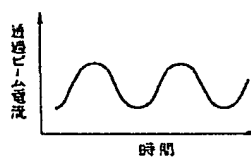


[Figure 3b]



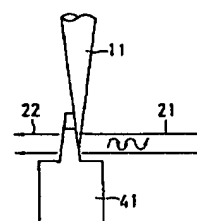
[Figure 3c]

[Y axis:] Transmission beam current
[X axis:] Time

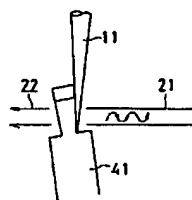


[Figure 3d]

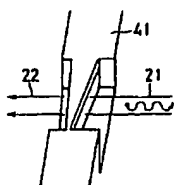
[Y axis:] Transmission beam current
[X axis:] Time



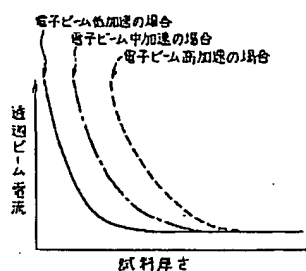
[Figure 3e]



[Figure 3f]



[Figure 3g]



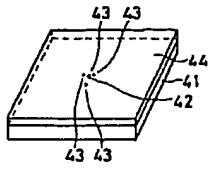
[Figure 3h]

[Y axis:] Transmission beam current
[X axis:] Sample thickness

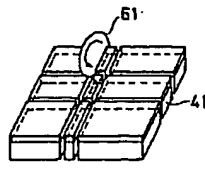
[In graph, left:] In the case of low acceleration of the electron beam

[In graph, middle:] In the case of medium acceleration of the electron beam

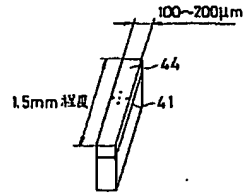
[In graph, right:] In the case of high acceleration of the electron beam



[Figure 4a]

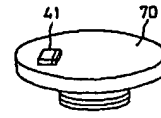


[Figure 4b]

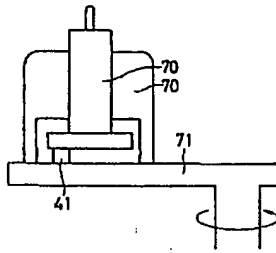


[Figure 4c]

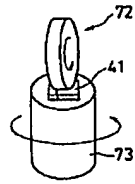
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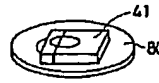
[Figure 4d]



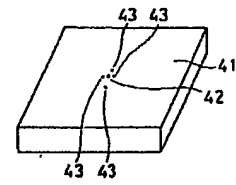
[Figure 4e]



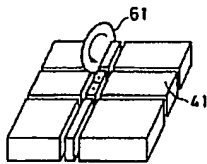
[Figure 4f]



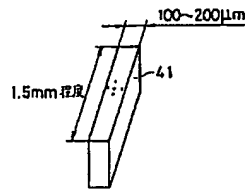
[Figure 4g]



[Figure 5a]

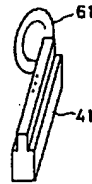


[Figure 5b]

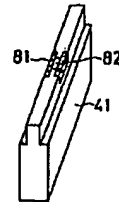


[Figure 5c]

[Key:] Approximately 1.5 mm



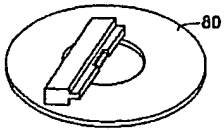
[Figure 5d]



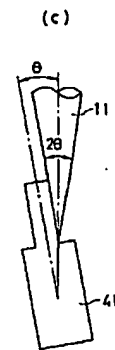
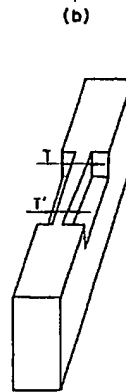
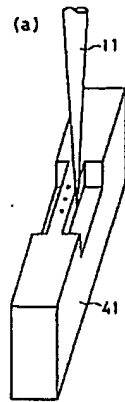
[Figure 5e]



[Figure 5f]



[Figure 5g]



[Figure 6]

Continued from the front page

(51) Int. Cl. ⁶	Identification Symbol	JPO File No.	F1	Technical Indication
H 01 J 37/31		9172-5E		